## AD NUMBER

**AD006532**

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**AFAL ltr 17 Aug 1979**

TI-844

8 apr 53

WADC TECHNICAL REPORT 52-182

AD 6532



# THE EFFECT OF NUMBER OF DIALS ON QUALITATIVE READING OF A MULTIPLE DIAL PANEL

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*NOVEMBER 1952*

**WRIGHT AIR DEVELOPMENT CENTER**

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AF-WP-(B)-O-8 APR 53 250

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WADC TECHNICAL REPORT 52-182

# THE EFFECT OF NUMBER OF DIALS ON QUALITATIVE READING OF A MULTIPLE DIAL PANEL

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*Antioch College*

*November 1952*

*Aero Medical Laboratory*
*Contract No. AF 18(600)-50*
*RDO No. 694-31*

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

## FOREWORD

This study was conducted at Antioch College under USAF Contract No. AF 18(600)-50, Research and Development Order No. 694-31, "Principles of Instrument Presentation." The contract was administered by the Psychology Branch of the Aero Medical Laboratory, Wright Air Development Center, with Major Edward Cole acting as Project Engineer. Miss Eva Fischer and Mrs. Martha Wilson conducted the experiments and performed most of the data analysis.

## ABSTRACT

Three experiments are reported in which the time required to make qualitative readings of a panel of dials was determined as a function of the number of dials on the panel. The results indicate that reading time is approximately a linear function of number of dials on the panel. The slope of the line is about eighteen times greater when pointers are not aligned than when they are aligned at the nine o'clock position.

For aligned pointers, time increases directly with the distance of the misaligned pointer from the fixation point, either vertical or horizontal. When pointers are not aligned, time bears no regular relation to horizontal distance from fixation point, but increases regularly from top to bottom of panel. From these differences, it is hypothesized that the quantitative difference between performance under the two conditions may be due to qualitative differences in the manner of scanning the panel.

Practice effects are very large, and it is hypothesized that these may be due at least in part to the expansion of the visual form-field.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDING GENERAL:

Robert H Blount
ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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## THE EFFECT OF NUMBER OF DIALS ON QUALITATIVE READING OF A MULTIPLE DIAL PANEL.

## I. INTRODUCTION

There are few, if any, operational tasks in which an operator is required to read or monitor a single instrument. Ordinarily, several instruments must be monitored, the exact number depending upon the complexity of the equipment, the particular task of the operator, and the extent to which the monitoring operations are performed by automatic controls. Yet in studying instrument design, investigators have usually focused their attention on the factors leading to improved readability of the single instrument. Legibility of numerals, optimum graduation interval, stroke width and stroke length, the best length and width of pointer are some of the many factors which have been investigated in an attempt to make dials more readable.

It seems likely, however, that more improvement can be made in the overall performance of an operator by improving the design and arrangement of groups of instruments, than by any combination of improvements designed to facilitate the reading of single dials. The pioneer study by Warrick and Grether (6) in which they investigated the effect of aligning pointers on the time required to check-read a sixteen dial panel, showed that it took twice as long to check-read a panel when pointers were aligned in groups of four as when all the pointers on the panel were aligned in the same direction. This study led to others, which tried to find conditions leading to improved performance in check-reading a sixteen dial panel whose pointers were aligned. White (7) found that groups of 1 3/4" dials could be checked more quickly than groups of 1" or 2 1/2" dials. In the same report, he also describes the regular pattern of eye-movements used in checking the panel. A second experiment by White (8) failed to demonstrate significant time or error differences among five different pointer modifications. Morely and Suffield (4) demonstrated that in a watchkeeping situation there were no differences of practical importance between alignment of pointers at any of the four cardinal positions. These results might be summarized by saying that modifications which enable subjects to read instruments in groups rather than singly result in great improvements in performance; modifications which affect the dials within the groups result in only minor changes in performance.

The several studies by Jones, Milton and Fitts, (2,3) on pilots' eye-movements during instrument flight represent another approach to the investigation of groups of instruments. These authors were able to analyze the pilot's use of the instrument panel in terms of the frequency with which each instrument was fixated, the average duration of each fixation, and the proportion of all shifts of fixation from one instrument to another which were between any two given instruments. By these techniques, the effect of changing the arrangement of instruments can be evaluated, and each instrument can be studied as part of a total panel rather than in isolation.

It is usually assumed that as the number of instruments to be monitored is increased, the operator's task increases in complexity and difficulty. This assumption, however, has never been directly verified by experiment, nor has it ever been expressed quantitatively. The purpose of this experiment is to determine the functional relation between the number of instruments to be monitored (hereafter referred to as $N_D$) and the time required to monitor them.

The study is divided into two principal experiments: in Experiment I subjects were required to find a misaligned pointer on a panel of dials when all other pointers were aligned at the nine o'clock position. In Experiment II the subjects were required to find the one pointer which was not within a $45^{\circ}$ sector marked by a red line on the outside rim of the dial. In Experiment II pointers were not aligned, either over the whole panel or by rows or columns. A third minor experiment tested the effect of unused dials surrounding those which were "operative".

## II. EXPERIMENT I

### APPARATUS, PROCEDURE, SUBJECTS

<u>Apparatus</u>:

The apparatus used was a sliding mirror tachistoscope. This device permits the exposure of a large field with either subject control or experimenter control of the interval during which the field is visible. Figure 1 shows the arrangement of mirrors, fields, and light sources. During the pre-exposure phase, the subject views the lower field which serves as a pre-adaptation field and also has provision for the insertion of a fixation point on the illuminated surface. When the shutter is operated, the upper of the two mirrors is raised and the subject permitted to observe the stimulus field. At the conclusion of the exposure interval, the lower mirror is activated and rises, obscuring the stimulus field and bringing the pre-(now post) exposure field again into view. When the shutters are released, both mirrors, in firm contact, slide down to the original position. The two mirrors are activated by Leland rotary solenoids and are caused to slide in tracks which maintain them parallel. The transition time from the moment of energization to full opening of the shutter is of the order of 1-2 milliseconds. A high precision electronic timer is used in conjunction with the tachistoscope to provide controlled intervals from 10 milliseconds up to 10.99 seconds. The timer may be operated either by the experimenter, by the subject, or by a remote switching device.

The frame of the apparatus consists of a large box approximately 30" on the edge, divided by a horizontal plane to provide the two fields, approximately 12" by 25". The shutter is mounted on the upper part of the face so as to be centered on the upper of the two fields when open and is at a distance of twenty-eight inches from this field. A large mirror at $45^{\circ}$ places the lower field at the same apparent position when the shutter is closed. Removable and movable panels are provided for both fields in order that a variety

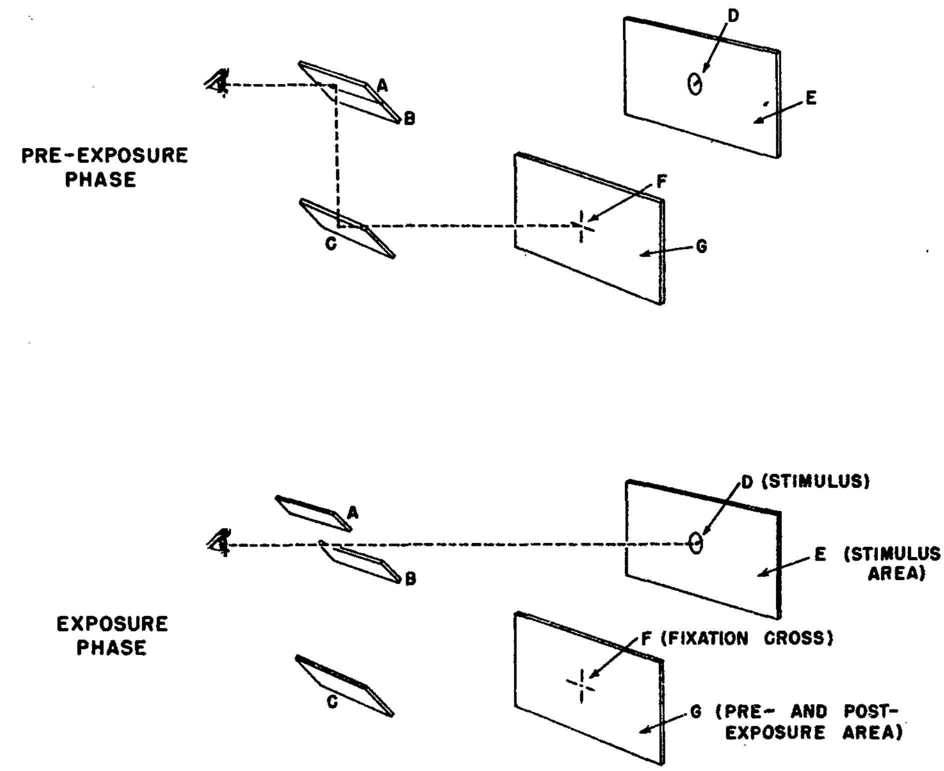



Figure 1. Schematic representation of the sliding mirror tachistoscope. A and B are sliding mirrors. C is stationary mirror. Post-exposure phase is identical to pre-exposure phase.

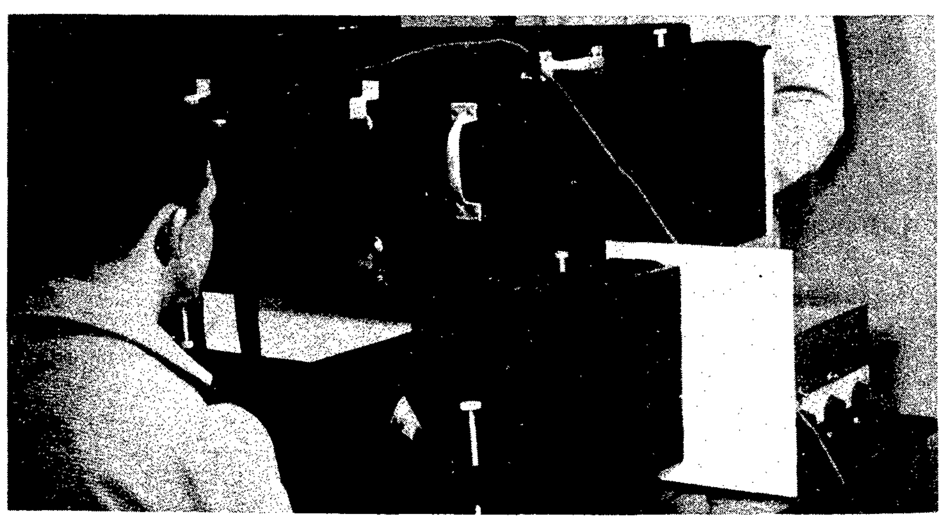


Figure 2. Subject in Position to Use Tachistoscope.

of pre-exposure and of stimulus materials may be used. Virtually uniform lighting is provided for the two fields by means of two pairs of light sources with diffusing screens and variable width gratings which may be controlled continuously from full illumination to very low illumination. Colored filters may also be inserted. Figure 2 shows a subject in position to use the apparatus.

In this experiment, the subject always controlled the duration of each exposure. He pressed the thumb switch which opened the shutter and started a clock, and then released the switch, which closed the shutter and stopped the clock. In the back of the tachistoscope was a panel of forty-five standard oil pressure dials 1 3/4" in diameter, spaced 2" apart, on center. The background and dial faces were black, while pointers and markings were pale yellow. The direction of each pointer could be changed by turning a knob on the back of the panel. Over the panel was fitted one of eight cardboard masks, which blocked from sight all dials except the ones to be checked during a particular session. The subjects therefore saw what appeared to be black panels with different numbers of dials on them. It was not possible with this apparatus to keep the shape of the panels constant and still have a wide range of values of $N_D$. For some panels the dials were arranged in a square, while for others they were arranged in rectangles with the long dimension horizontal. The number and arrangement of the dials on the panels was as follows:

| $N_D$ | Arrangement |
|---|---|
| 1 | 1 x 1 |
| 2 | 2 x 1 |
| 4 | 2 x 2 |
| 8 | 4 x 2 |
| 16 | 4 x 4 |
| 24 | 6 x 4 |
| 32 | 8 x 4 |
| 45 | 9 x 5 |

The panels were illuminated by light sources located in the sides of the tachistoscope. Two conditions of illumination were used: white light of approximately 1.5 ft. lamberts, and red light of approximately .003 ft. lamberts. The experimental room was lighted only enough to enable the experimenter to operate the apparatus and record results and to enable the subject to record results in an answer booklet.

Procedure:

In a typical experimental session the subject entered the room and was seated at the tachistoscope. Its purpose and operation were explained to him, and he was then told:

"This is an experiment to determine in what way the time required to read an instrument panel depends upon the number of instruments on the panel. You will see an instrument panel with some number of dials on it. The number may be as small as one or as large as forty-five. All the dials except one will have their pointers at the 9 o'clock position -- that is, horizontal and pointing to the left. One dial will be misaligned. Its pointer will be either forty-five degrees above or below this position. You are to find which pointer is misaligned and in which direction." It was explained to the subject that prior to each trial he was to look at the fixation point, which was located in a spot corresponding to the center of the dial panel.

Subjects were given answer booklets, which consisted of circles arranged in the same way as the dials on the panel. There was a set of circles for each trial. The subject was told to make a pencil mark on the circle corresponding to the dial with the misaligned pointer, in the direction in which the pointer was misaligned. (We could have used a bank of three-position toggle switches but the use of answer booklets had one major advantage over this procedure: the time recorded for each trial was the time required to locate the dial whereas if we had included also the time to locate the appropriate toggle switch, we would not have been able to separate the effects of increasing number of dials from the effects of increasing the number of switches. Or we could have had the subject describe orally the location of the dial whose pointer was misaligned (hereafter called $D_m$) but the use of answer booklets minimized the chance that a subject would perceive $D_m$ correctly but be unable to verbalize its location. Subjects were, however, encouraged to verbalize the location if they felt that this procedure helped them.)

The subject was given three practice trials, or several more if he requested them, before beginning the test trials on any panel. Finally he was told: "Each trial will be timed, so try to work as rapidly as possible." The experimenter then misaligned a pointer according to a prearranged sequence, called "Ready" and the subject operated the shutter and recorded his result. This procedure was continued for twenty-four trials, after which the mask was changed. The procedure was repeated. Four masks were used in one experimental session, which required about forty-five minutes. Each subject served in four experimental sessions, two under each condition of illumination.

## Experimental Design:

The experimental design is summarized in Figure 3. The purpose of the design was to balance serial effects among eight panels or masks, and between two conditions of illumination. Group I received all panels first under white light, then under red. This order was reversed for Group II. Group III received a counterbalanced order of white light, red light, red light, and white light. Within each block in the above figure each of eight subjects was tested with each of the eight masks. The order in which the subjects were tested with the masks was such that each mask occurred once in each serial position, and each mask followed every other mask once. (See p. 29, Appendix I.) A subject received the masks in the same order under both illumination conditions.

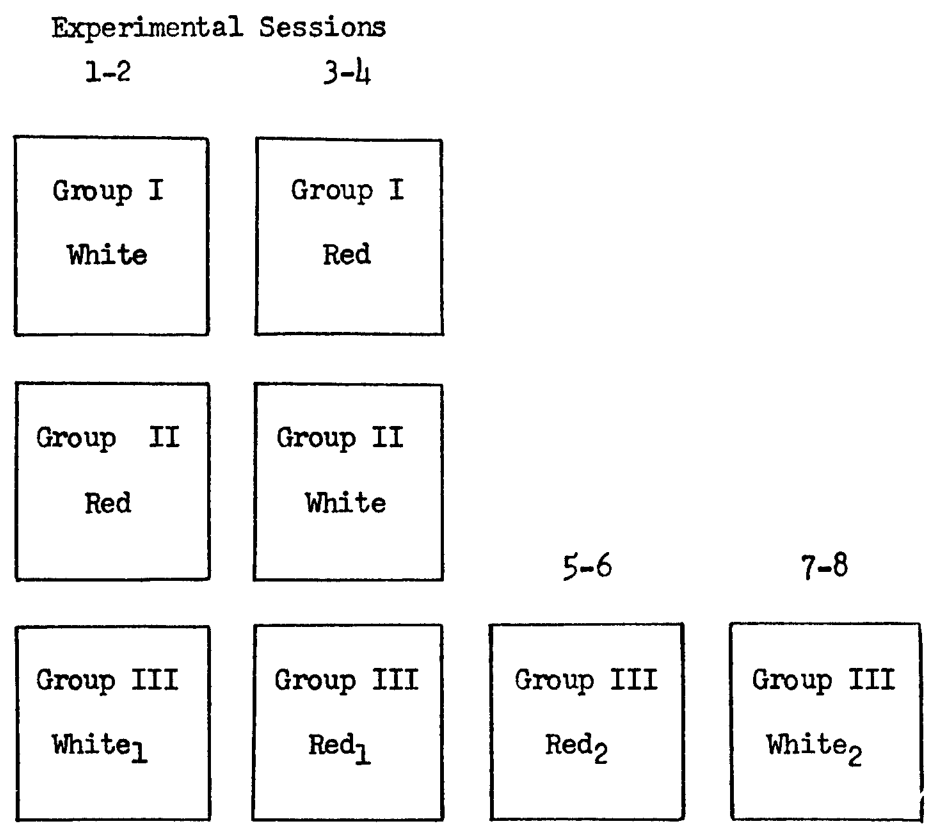



Figure 3.
Experimental Design

For each of the twenty-four trials on a particular mask, $D_m$ was chosen by partial randomization. On the smaller panels all the dials were misaligned the same number of times. On the larger masks, $D_m$ occurred the same number of times in each quadrant of the panel, and every dial had its pointer misaligned several times during the course of the experiment.

Subjects:

The subjects were twenty-four students at Antioch College. No attempt was made to equate the three groups in any way, and certain differences existed among them, particularly in age.

| | Mean Age | Mdn. Age | Men | Women |
|---|---|---|---|---|
| Group I | 19 yrs. 11 mos. | 19 yrs. 8 mos. | 2 | 6 |
| Group II | 18 yrs. 7 mos. | 18 yrs. 8 mos. | 5 | 3 |
| Group III | 21 yrs. 11 mos. | 21 yrs. 5 mos. | 3 | 5 |

## RESULTS

The results of Experiment I are based on a total of 12,176 responses, 3044 from Group I, 3044 from Group II, and 6088 from Group III.

Effect of $N_D$ :

The results are summarized in Table I, which presents, separately for each group, for each illumination, and for each $N_D$, the mean time,

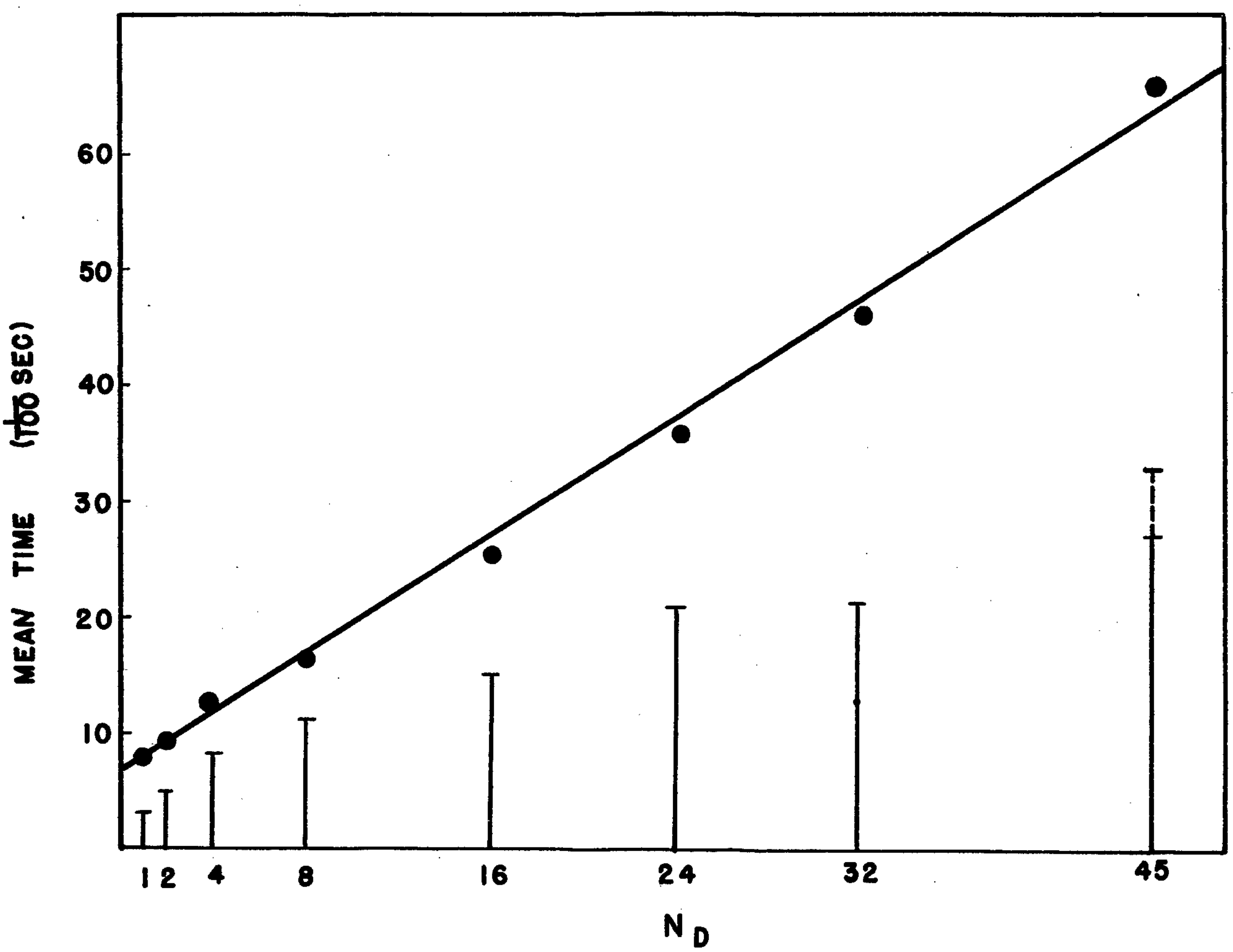



Figure 4. Mean time per panel in 1/100 sec. as a function of $N_D$. The vertical columns represent the mean standard deviation of the individual subject's mean scores around the means of their own groups. ($\sigma_g$). The dashed line includes one anomalous subject. (See p. 17.)

## TABLE I

Mean times per group, means of individual standard deviations ($\sigma_i$), and standard deviations of individual means around group mean ($\sigma_g$), in 1/100 seconds.

| Group | | $N_D$: 1 | 2 | 4 | 8 | 16 | 24 | 32 | 45 | |
|---|---|---|---|---|---|---|---|---|---|---|
| I W | $\bar{X}$ | 7.2 | 9.8 | 14.6 | 16.6 | 22.5 | 41.3 | 58.9 | 97.9 | |
| | $\sigma_i$ | 3.0 | 3.1 | 3.3 | 4.6 | 11.2 | 9.5 | 24.9 | 71.1 | (37.2)* |
| | $\sigma_g$ | 2.8 | 6.7 | 12.2 | 13.2 | 18.4 | 25.2 | 32.1 | 111.8 | (41.0)* |
| I R | $\bar{X}$ | 6.8 | 10.0 | 10.4 | 13.1 | 20.8 | 28.0 | 31.3 | 52.1 | |
| | $\sigma_i$ | 1.9 | 2.8 | 2.6 | 3.2 | 5.9 | 8.3 | 7.0 | 18.2 | |
| | $\sigma_g$ | 3.5 | 9.2 | 8.7 | 10.5 | 16.8 | 17.3 | 23.9 | 24.3 | |
| II R | $\bar{X}$ | 11.1 | 12.1 | 10.5 | 15.2 | 22.9 | 30.3 | 35.0 | 42.8 | |
| | $\sigma_i$ | 3.7 | 3.3 | 2.7 | 4.7 | 9.2 | 8.4 | 11.5 | 16.1 | |
| | $\sigma_g$ | 5.2 | 6.3 | 4.5 | 11.5 | 17.8 | 27.2 | 25.7 | 23.9 | |
| II W | $\bar{X}$ | 6.2 | 6.7 | 8.0 | 11.6 | 15.3 | 23.1 | 29.3 | 34.9 | |
| | $\sigma_i$ | 2.3 | 2.3 | 2.5 | 3.2 | 4.5 | 6.2 | 10.1 | 13.0 | |
| | $\sigma_g$ | 3.2 | 3.9 | 4.1 | 6.6 | 10.0 | 16.1 | 19.0 | 25.4 | |
| III $W_1$ | $\bar{X}$ | 9.7 | 13.8 | 24.8 | 36.4 | 51.0 | 70.8 | 81.7 | 114.7 | |
| | $\sigma_i$ | 2.9 | 4.5 | 7.3 | 9.5 | 13.4 | 24.4 | 27.6 | 44.4 | |
| | $\sigma_g$ | 3.1 | 3.5 | 21.9 | 26.1 | 20.6 | 31.6 | 25.0 | 30.0 | |
| III $R_1$ | $\bar{X}$ | 8.3 | 8.4 | 13.7 | 17.0 | 33.8 | 42.5 | 51.4 | 70.8 | |
| | $\sigma_i$ | 3.1 | 2.7 | 4.1 | 5.1 | 7.6 | 11.7 | 14.2 | 24.6 | |
| | $\sigma_g$ | 2.3 | 2.3 | 8.1 | 12.5 | 14.3 | 19.4 | 16.1 | 23.3 | |
| III $R_2$ | $\bar{X}$ | 7.4 | 7.6 | 10.0 | 9.4 | 19.8 | 25.9 | 41.3 | 60.0 | |
| | $\sigma_i$ | 2.2 | 2.1 | 2.7 | 3.1 | 5.4 | 7.1 | 12.1 | 18.8 | |
| | g | 2.2 | 2.9 | 4.7 | 4.6 | 14.9 | 17.7 | 16.5 | 19.3 | |
| III $W_2$ | $\bar{X}$ | 6.3 | 6.1 | 8.1 | 7.9 | 12.5 | 23.7 | 36.8 | 56.7 | |
| | $\sigma_i$ | 1.8 | 2.1 | 2.0 | 2.2 | 3.9 | 6.2 | 15.6 | 23.7 | |
| | $\sigma_g$ | 2.2 | 1.8 | 3.8 | 3.6 | 8.6 | 15.6 | 11.5 | 5.8 | |
| Total | $\bar{X}$ | 7.9 | 9.3 | 12.5 | 15.9 | 24.8 | 35.7 | 45.7 | 66.2 | |
| | $\sigma_i$ | 2.6 | 2.9 | 3.4 | 4.9 | 7.6 | 10.2 | 15.4 | 28.7 | (24.5)* |
| | $\sigma_g$ | 3.0 | 4.6 | 8.5 | 11.0 | 15.2 | 21.3 | 21.2 | 33.6 | (27.2)* |

*Score of one anomalous subject omitted. See p. 17.

the mean of the standard deviations computed for each subject around his own mean ($\sigma_i$), and the standard deviation of the eight subjects' means around the group mean ($\sigma_g$). In Figure 4, the mean time for all groups and conditions combined is plotted as a function of $N_D$.

The data are approximately linear, and a straight line has been fitted by eye and drawn through the points. It may be argued with some justice that the data could be better fitted by two straight lines or by a curve, but there is not enough evidence available for a parametric test of the fit of the curve, and within the values of $N_D$ investigated, the straight line fit serves as an entirely satisfactory working description.

For each subject, the standard deviation of the twenty-four scores obtained under a given experimental condition ($N_D$, and illumination) around the mean of those twenty-four scores was computed. These standard deviations were averaged over all subjects in a group and this group average is listed as $\sigma_i$ in Table I.

A standard deviation based on the deviations of the individual subject's means around the mean of their own group was also computed, separately for each of the eight groups or conditions. These standard deviations are artificially enlarged by the fact that they include the first trial for one subject, the second trial for one subject, and so on. As will be seen, practice has a tremendous effect on time scores, and the result of balancing practice effects with any $N_D$ is to make $\sigma_g$ appear too large. For all conditions combined the average $\sigma_g$ is represented (also in 1/100 seconds) by the height of the vertical lines at the bottom of Figure 4. ($\sigma_g$ was computed by the small sample formula, with N-1 in the denominator.)

## Effect of Illumination:

From the data of Table I, the scores for all groups working under red illumination may be combined, and those for white illumination may also be combined.

The times for red light are consistently below those for white light (except for the two lowest points where there is practically no difference). This would be surprising, were it not for the fact that these results are contaminated by group differences and by practice effects. It will be shown (p. 16) that the greatest improvement in performance occurs during the first eight trials, and as Figure 3 shows, Groups I and III were both tested on white light on these first trials. Group II, which was tested first with red light, was the fastest group (and the group with the most errors) and made the least improvement during the first trials. If only scores from groups which have had at least eight practice trials are considered, the times for white light are less than those for red. At present, the conclusion that there is any real time difference between the two conditions is unwarranted.

The fact that there was not a large performance difference favoring white light is surprising enough. Visual and perceptual tasks are usually performed significantly faster under high illumination than under low, and we would expect the same results with this task. Several of the subjects reported, however, that under the dim red light the graduations on the dials were barely visible, which made the long horizontal line of the aligned pointers stand out more strikingly against the black background than it had under the brighter, white light. This suggestion might be made the basis for further research.

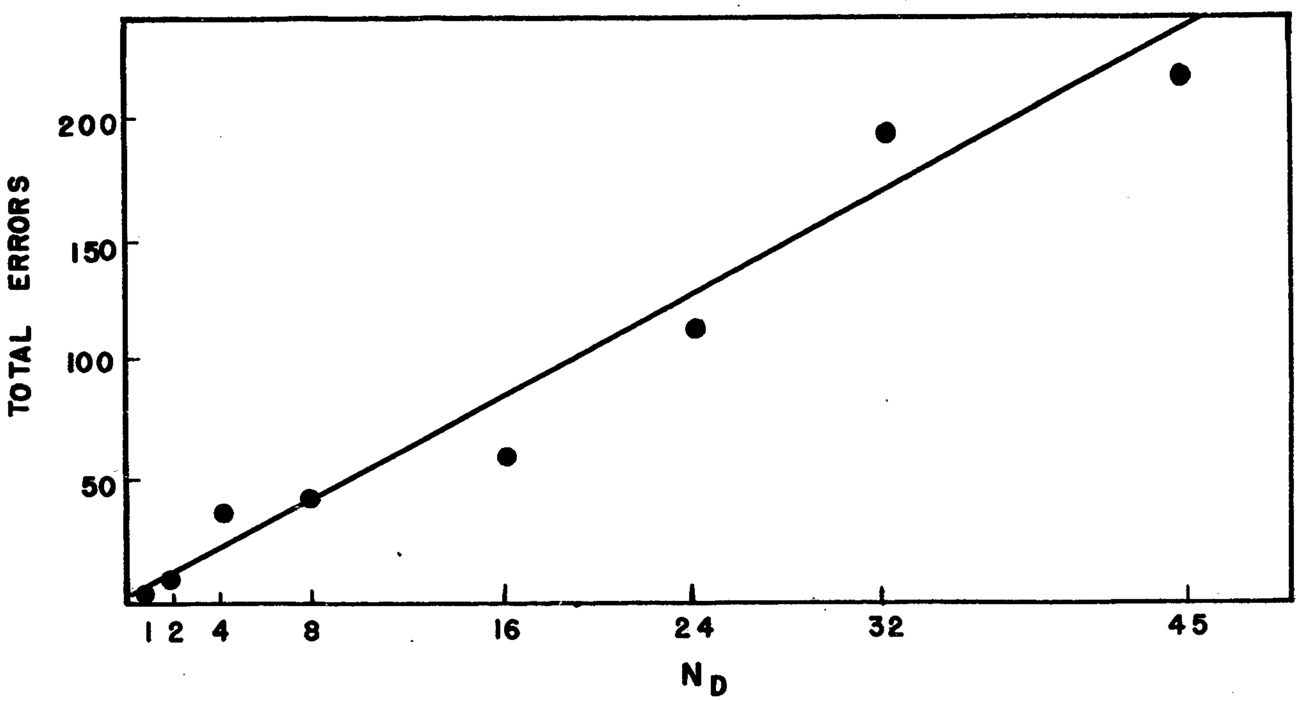
Errors:

A response was scored as an error if the wrong circle in the answer booklet was marked or if the mark was in the wrong direction. The total number of errors for each group and each illumination condition is presented in Table II as a function of $N_D$. From this table and from Figure 5, where total number of errors is plotted as a function of $N_D$, it may be seen that errors increase as $N_D$ increases, although it is not possible from these data to describe the mathematical form of the relationship. It may also be seen that there are striking differences between the groups in the number of errors which occur. Group II, the fastest group, has 9.6% of its responses in error, while Group III, the slowest group, is in error only 2.6% of the time. These differences in error frequencies, which are negatively related to time scores, are also correlated with differences in attitude toward the experiment as seen by the experimenter. Members of Group III, an older group, were very serious about the purpose of the experiment, and very little concerned with their own performance. They were task-involved, rather than ego-involved. Of Group II, the youngest group, the opposite could be said. Members of that group tended to regard the experiment as a sort of athletic contest with laurels going to the fastest subjects.

TABLE II

Error Frequencies

| | $N_D$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Group | 1 | 2 | 4 | 8 | 16 | 24 | 32 | 45 | Tot. | | % |
| I W | 0 | 1 | 5 | 8 | 14 | 20 | 26 | 36 | 110 | | |
| I R | 0 | 2 | 7 | 5 | 9 | 18 | 31 | 33 | 105 | 215 | 7.0 |
| II R | 1 | 2 | 7 | 16 | 14 | 25 | 49 | 46 | 160 | | |
| II W | 1 | 1 | 6 | 3 | 11 | 18 | 37 | 47 | 135 | 295 | 9.6 |
| III $W_1$ | 0 | 0 | 2 | 5 | 5 | 5 | 13 | 9 | 39 | | |
| III $R_1$ | 0 | 1 | 5 | 2 | 3 | 7 | 12 | 17 | 47 | | |
| III $R_2$ | 0 | 0 | 4 | 1 | 4 | 12 | 12 | 17 | 50 | 177 | 2.6 |
| III $W_2$ | 0 | 0 | 0 | 2 | 2 | 9 | 14 | 14 | 41 | | |
| Total | 2 | 8 | 36 | 42 | 62 | 114 | 194 | 219 | 687 | | |




($N_D$)

Figure 5. Total errors, all conditions combined, as a function of $N_D$.

There is some evidence to indicate that more errors occurred under red light than under white, with frequencies of 362 as compared to 325, but the difference is not statistically significant.

Location of $D_m$:

For every panel, each pointer was misaligned several times during the course of the experiment. This means that a mean time can be computed for each dial, and these means are given in Appendix II. From these data, the grand mean for each column and for each row of dials was computed, and these results are plotted in Figures 6 and 7, as a function of the displacement of that row or column from the fixation point. What these figures tell us, then, is the way in which time varies as $D_m$ is moved farther away from the fixation point, either vertically or horizontally.

These two families of curves have several interesting features. 1) In both families, all curves (where there are enough points to make this possible) are U-shaped, indicating that the more distant from the fixation point, either horizontally or vertically, is a dial, the greater is the time required to locate that dial. 2) In Figure 6, the points corresponding to the upper half of the panel are lower than those corresponding to the lower half, indicating that if a dial is located below the fixation point, more time is required to find it than if it is above. 3) Not all the increase in time with an increase in $N_D$ is due to the peripheral dials,

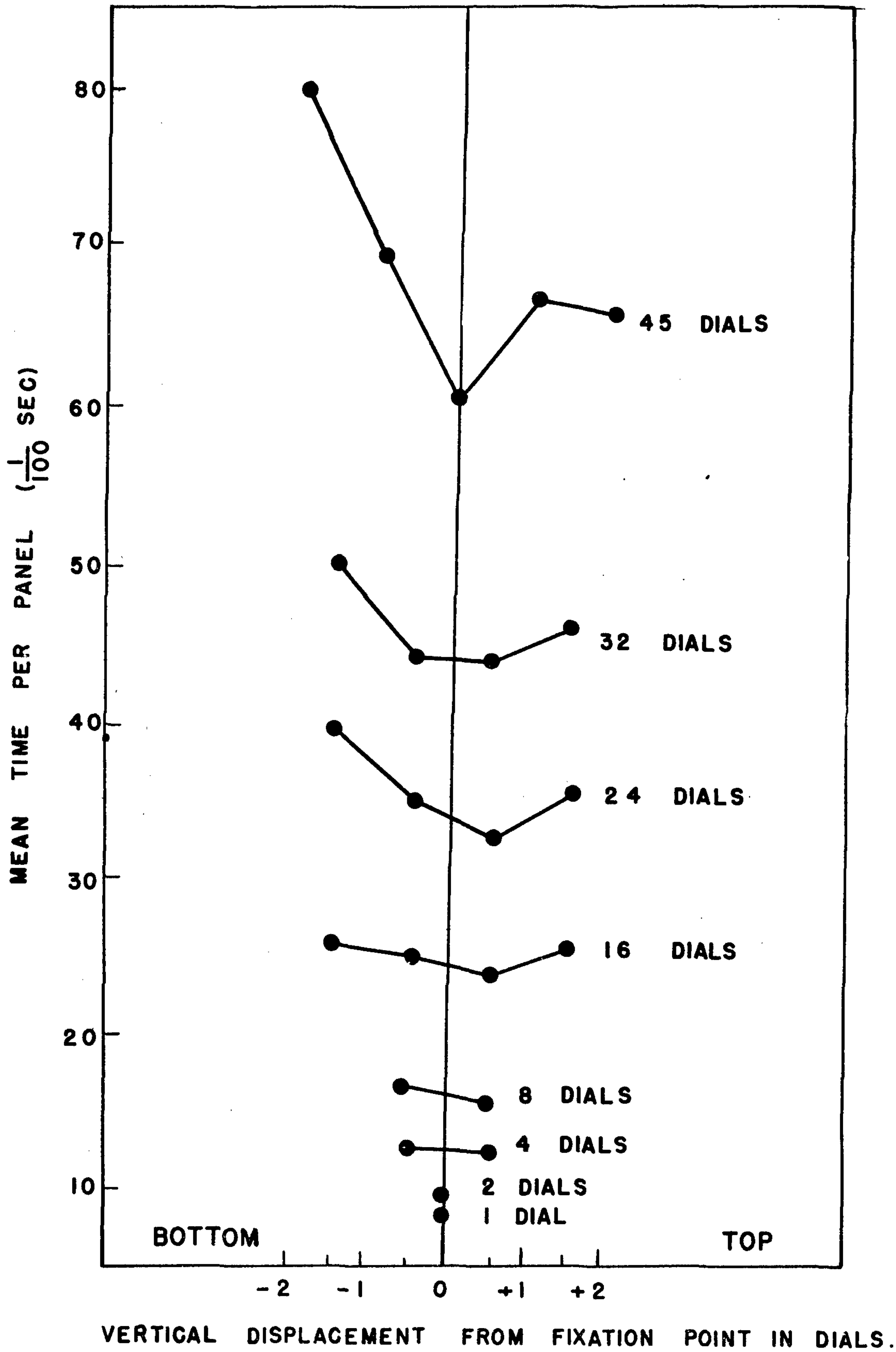



Figure 6. Mean time per panel as a function of vertical displacement of $D_m$ from fixation point.

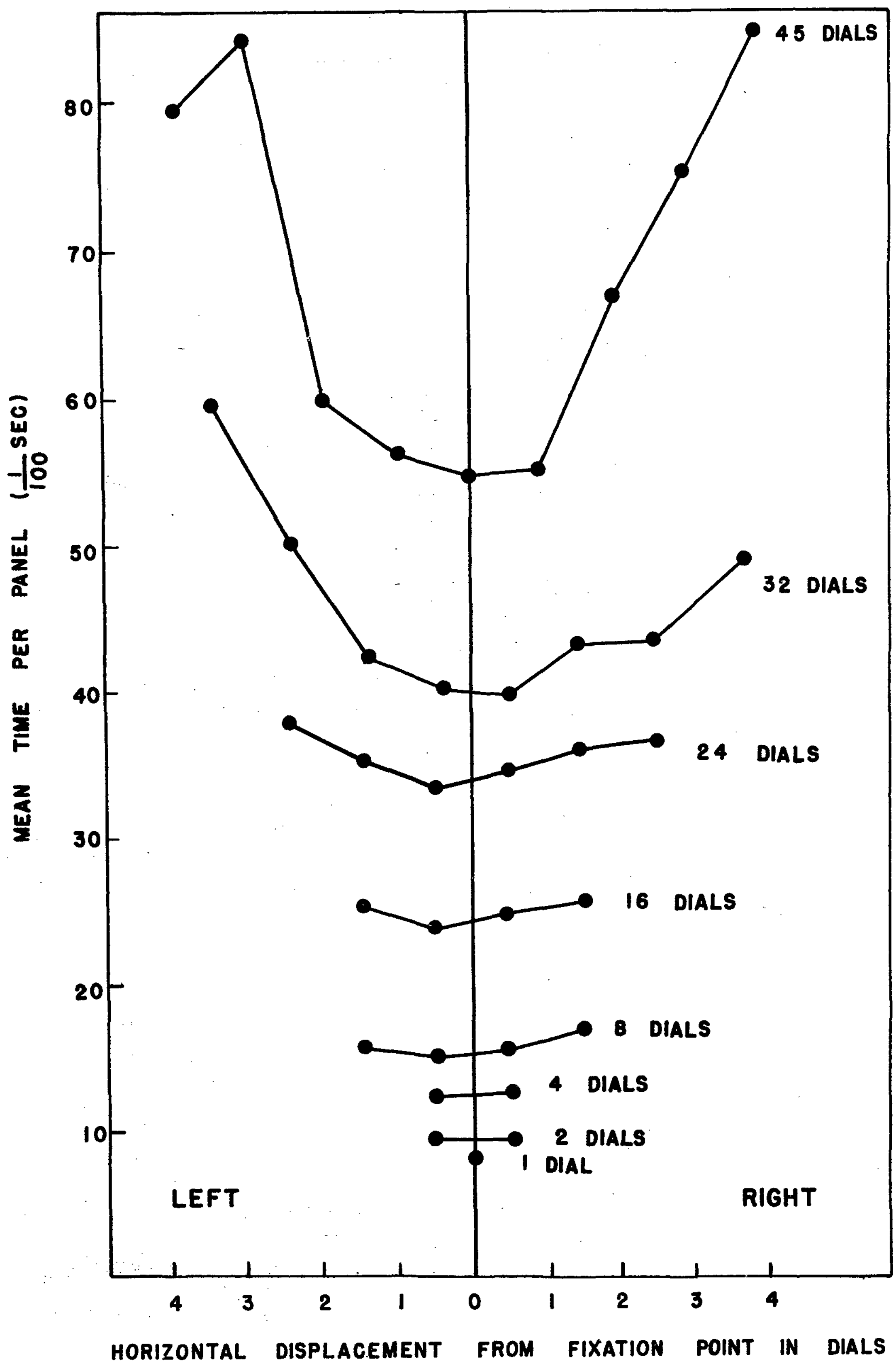



Figure 7. Mean time per panel as a function of horizontal displacement of $D_m$ from fixation point.

as is indicated by the fact that there is a steady increase in the time at which the curves cross the line representing the fixation point. In other words, it takes from six to seven times as long to check the center dial on a forty-five dial panel as to check a dial standing by itself. 4) There seems to be some tendency for the limbs of the U to become steeper as $N_D$ is increased, but there are not enough points to be certain of this conclusion.

In summary, the greater the distance between $D_m$ and the fixation point, the longer it takes, on the average to find $D_m$. If $D_m$ is in the bottom half of the panel a longer time will be required to find it than if it is in the upper half. But there is no evidence that the times for $D_m$'s on the left side of the panel are lower than those on the right (as we might expect from White's (7) report.) In fact, times actually seem to be slightly higher for the left.

## Effect of Practice:

Table III and Figures 8 and 9 present the mean time and $\sigma_i$ for each experimental group as a function of trials. Each point is the average of eight subjects, each being tested on a different dial panel. (A point is the mean of one subject on the 45 dial panel, one on the 32, and so on, including all eight different panels.) From these data it can be seen that both time and variability show a large decrease during the first two or three trials and continue to decrease over a much longer series of trials. Group III's means have apparently not reached an asymptote even after thirty-two trials of 24 responses each.

Observations of the subjects and their introspections suggest that there are three principal factors involved in this improvement with practice. First, there was probably some improvement in the operation of the shutter by the subjects. Some of them, particularly some in Group II, discovered "tricks" for making the shutter operate fast; Group III was specifically instructed in such a way as to avoid this artifact. Relative to the total improvement, improvement due to this factor was probably small. Second, the subjects probably learned, as the experiment progressed, to improve their technique of making tachistoscopic observations. In the beginning, most subjects would open the shutter, look, and then release the shutter. Later they learned that the opening and release of the shutter could be performed in a single motor act, and the resultant exposure would usually be long enough to locate $D_m$. There is evidence that more and more of them did this as the experiment progressed.

The third factor is the expansion of the visual form-field. This has been defined by Renshaw (5) as "the solid angle within and beyond the region of the anatomical macula in which an observer is able to see shapes." Renshaw demonstrated that the form-field could be greatly enlarged by tachistoscopic training, and Christensen (1) has demonstrated in an unpublished study that such training may affect and improve performance in multiple dial reading. So striking was the effect of expansion of the form-field in the present experiment that the subjects themselves coined a name for it, saying, "My eye-span has increased." One subject even quantified her estimate, saying that her eye-span had increased from four to twenty-four dials. One subject in Group I provided a particularly convincing demonstration of this

## TABLE III

Mean times and mean $\sigma_i$ (1/100 sec.) and total errors as a function of trials.

| Trial | Group I $\bar{X}$ | Group I $\sigma_i$ | Group I E | Group II $\bar{X}$ | Group II $\sigma_i$ | Group II E | Group III $\bar{X}$ | Group III $\sigma_i$ | Group III E |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 77.8 | 45.3 | 10 | 42.8 | 13.0 | 21 | 59.8 | 20.5 | 11 |
| 2 | 32.1 | 9.1 | 13 | 31.8 | 10.4 | 21 | 55.1 | 17.9 | 4 |
| 3 | 26.7 | 14.6 | 25 | 19.4 | 5.8 | 19 | 64.4 | 24.8 | 5 |
| 4 | 34.6 | 11.4 | 12 | 18.0 | 6.0 | 14 | 48.9 | 18.5 | 3 |
| 5 | 28.2 | 11.4 | 18 | 21.4 | 6.7 | 19 | 45.8 | 15.0 | 2 |
| 6 | 22.3 | 15.6 | 16 | 21.8 | 9.4 | 18 | 39.4 | 11.5 | 8 |
| 7 | 27.8 | 17.4 | 11 | 13.3 | 4.8 | 28 | 46.9 | 13.2 | 2 |
| 8 | 23.7 | 15.8 | 5 | 12.4 | 3.5 | 14 | 42.5 | 11.4 | 4 |
| 9 | 26.6 | 1.9 | 14 | 21.4 | 7.2 | 22 | 34.1 | 11.7 | 5 |
| 10 | 21.7 | 8.0 | 15 | 24.7 | 8.5 | 11 | 24.8 | 5.7 | 4 |
| 11 | 20.4 | 5.3 | 17 | 13.3 | 3.2 | 19 | 28.0 | 9.7 | 13 |
| 12 | 22.7 | 6.1 | 14 | 14.1 | 4.2 | 17 | 31.6 | 5.5 | 4 |
| 13 | 21.4 | 5.6 | 13 | 18.5 | 6.6 | 10 | 31.4 | 7.8 | 6 |
| 14 | 20.1 | 3.3 | 12 | 17.1 | 7.2 | 16 | 31.8 | 11.4 | 3 |
| 15 | 19.4 | 7.1 | 12 | 12.1 | 2.6 | 18 | 32.5 | 8.5 | 3 |
| 16 | 20.3 | 12.2 | 8 | 11.8 | 4.8 | 12 | 31.8 | 7.3 | 9 |
| 17 | | | | | | | 29.6 | 10.8 | 7 |
| 18 | | | | | | | 18.6 | 4.2 | 8 |
| 19 | | | | | | | 19.2 | 6.1 | 9 |
| 20 | | | | | | | 18.6 | 5.6 | 7 |
| 21 | | | | | | | 23.5 | 5.1 | 3 |
| 22 | | | | | | | 26.2 | 7.0 | 2 |
| 23 | | | | | | | 23.7 | 6.2 | 7 |
| 24 | | | | | | | 21.9 | 8.4 | 7 |
| 25 | | | | | | | 21.5 | 6.7 | 5 |
| 26 | | | | | | | 22.9 | 6.5 | 2 |
| 27 | | | | | | | 18.6 | 8.5 | 9 |
| 28 | | | | | | | 18.9 | 7.5 | 4 |
| 29 | | | | | | | 21.7 | 6.1 | 2 |
| 30 | | | | | | | 17.9 | 6.9 | 10 |
| 31 | | | | | | | 19.1 | 7.0 | 5 |
| 32 | | | | | | | 17.2 | 8.4 | 4 |

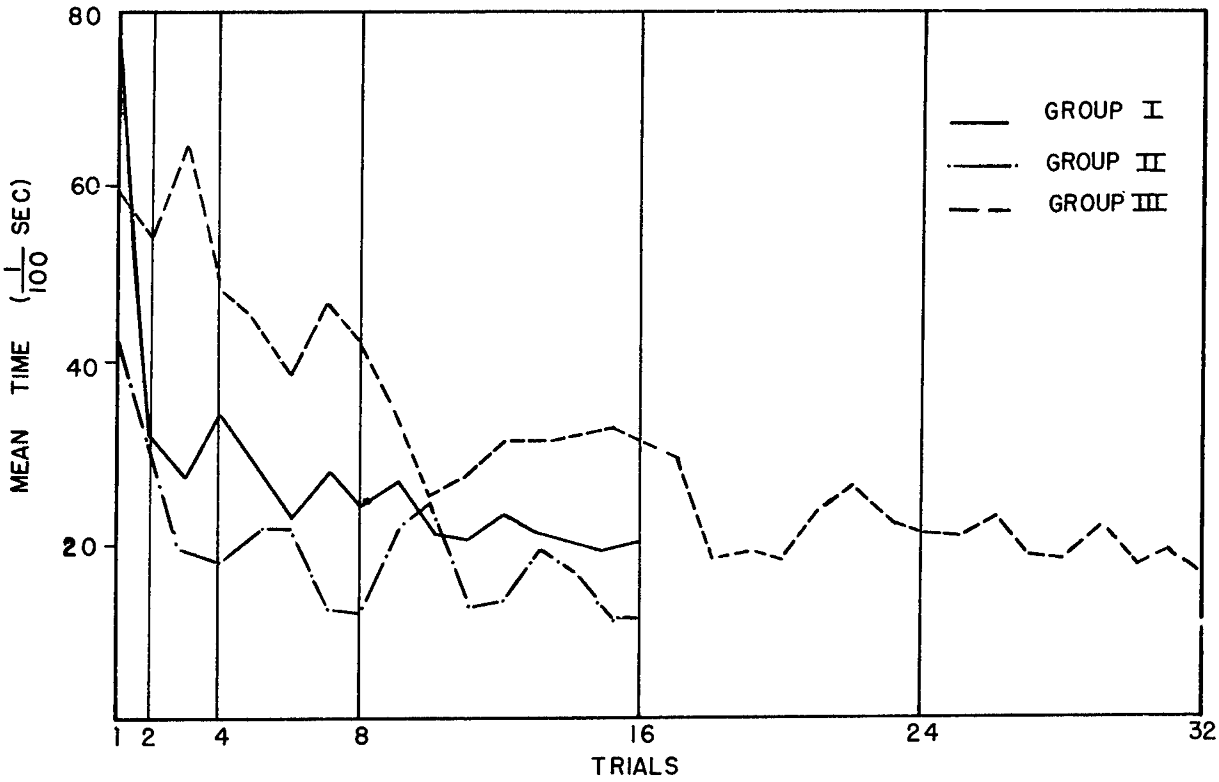



Figure 8. Mean time per panel as a function of numbers of trials.

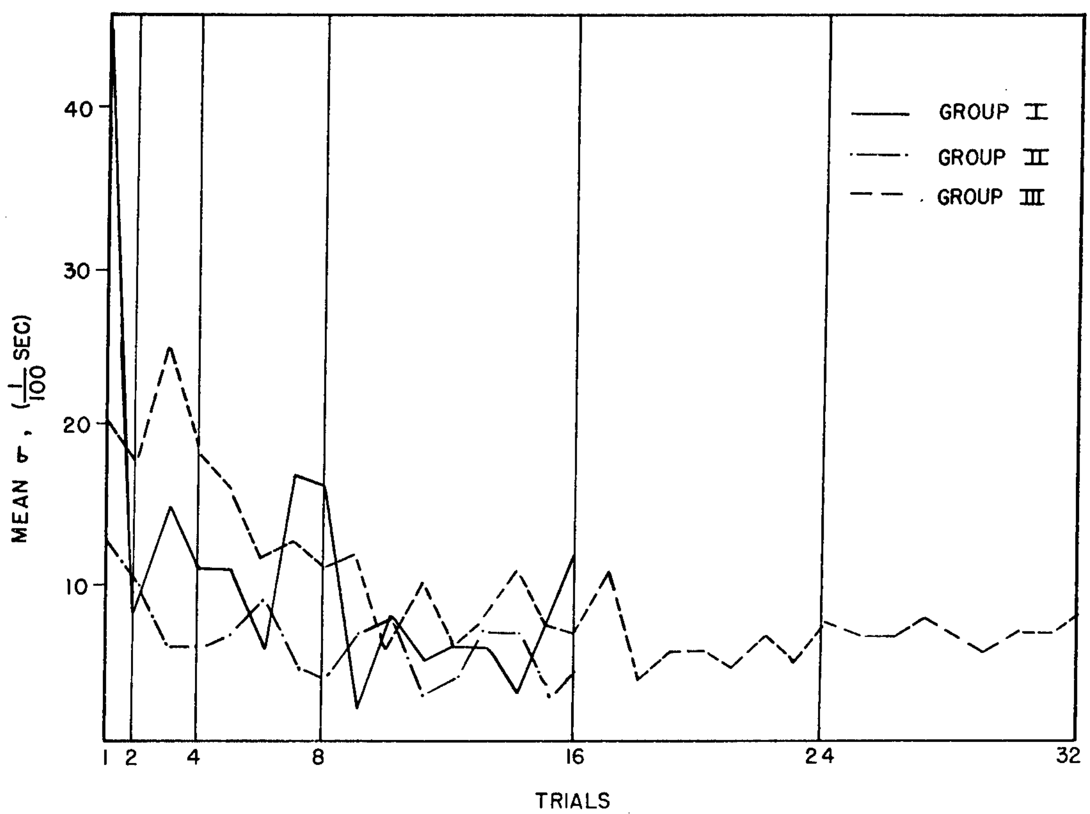



Figure 9. Mean $\sigma_i$ per panel as a function of trials.

phenomenon. She misunderstood the instructions and throughout all her sixteen trials operated under the misapprehension that she was not to move her eyes at all but was to continue to fixate the spot where the fixation point had been before the shutter opened. On her first trials her means were far outside the distribution of scores of the rest of the group, but with practice she was able to check-read even the forty-five dial panel with long but not abnormal times, and with no eye-movements. She was one of those who explained her own improvement by reference to her "eye-span".

If the increase in form-field was an important factor in reducing times we would expect to find that times for $D_m$'s distant from the fixation point decreased more with practice than for those near it. Fortunately the data are available to test this deduction directly. Times for the first eight trials of all three groups may be combined to give an estimate for unpracticed subjects, and the rest of the data are combined to give an estimate for practiced subjects. The data so divided may then be analyzed to give the mean time per panel as a function of displacement of $D_m$ from the fixation point. These data are now comparable to those of Figure 5, except that they are divided into practiced and unpracticed trials. For the forty-five dial panel, mean time as a function of horizontal displacement of $D_m$ from the fixation point for practiced and unpracticed subjects has been plotted in Figure 10. From this figure it may be seen that the proportional decrease with practice is much greater for the peripehral dials than for the central ones.

Errors have not been plotted as a function of trials, but an examination of Table III reveals that there is only a slight tendency for errors to decrease with practice. Subjects apparently worked for more speed and not for more accuracy.

The decrease in time scores as a result of practice is so great, that we may wonder what the function of time vs. $N_D$ would look like for practiced subjects. Pilots, flight engineers, and others who customarily read or monitor dials would be comparable to practiced subjects and not to subjects who were inexperienced. Results from the first eight trials of all groups have been combined and are plotted in the upper curve of Figure 11. All other results have been combined and are plotted in the bottom curve.

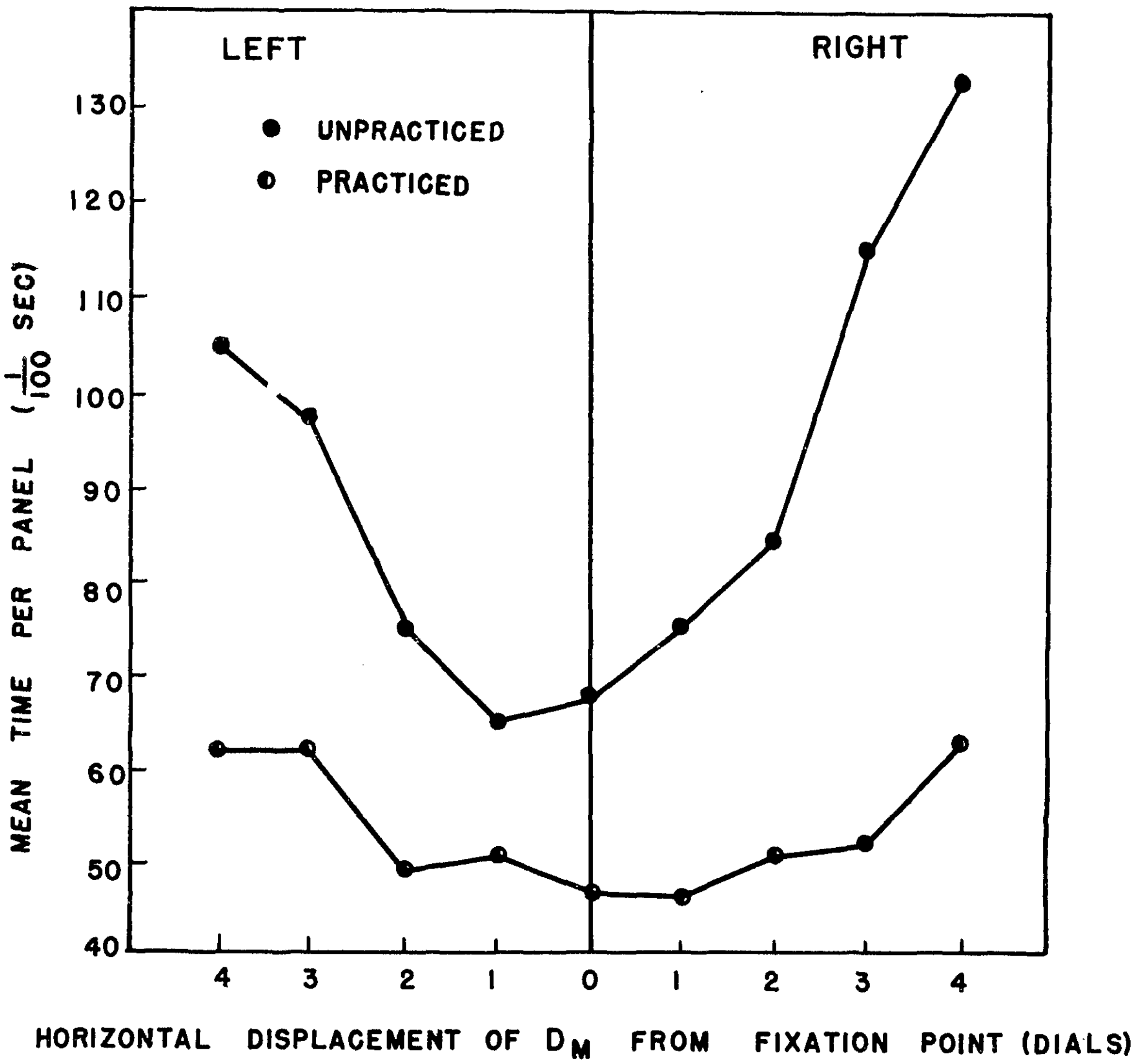



Figure 10. Time per panel as a function of horizontal displacement of $D_m$ from fixation point. Practiced vs. unpracticed subjects on 45 dial panel.

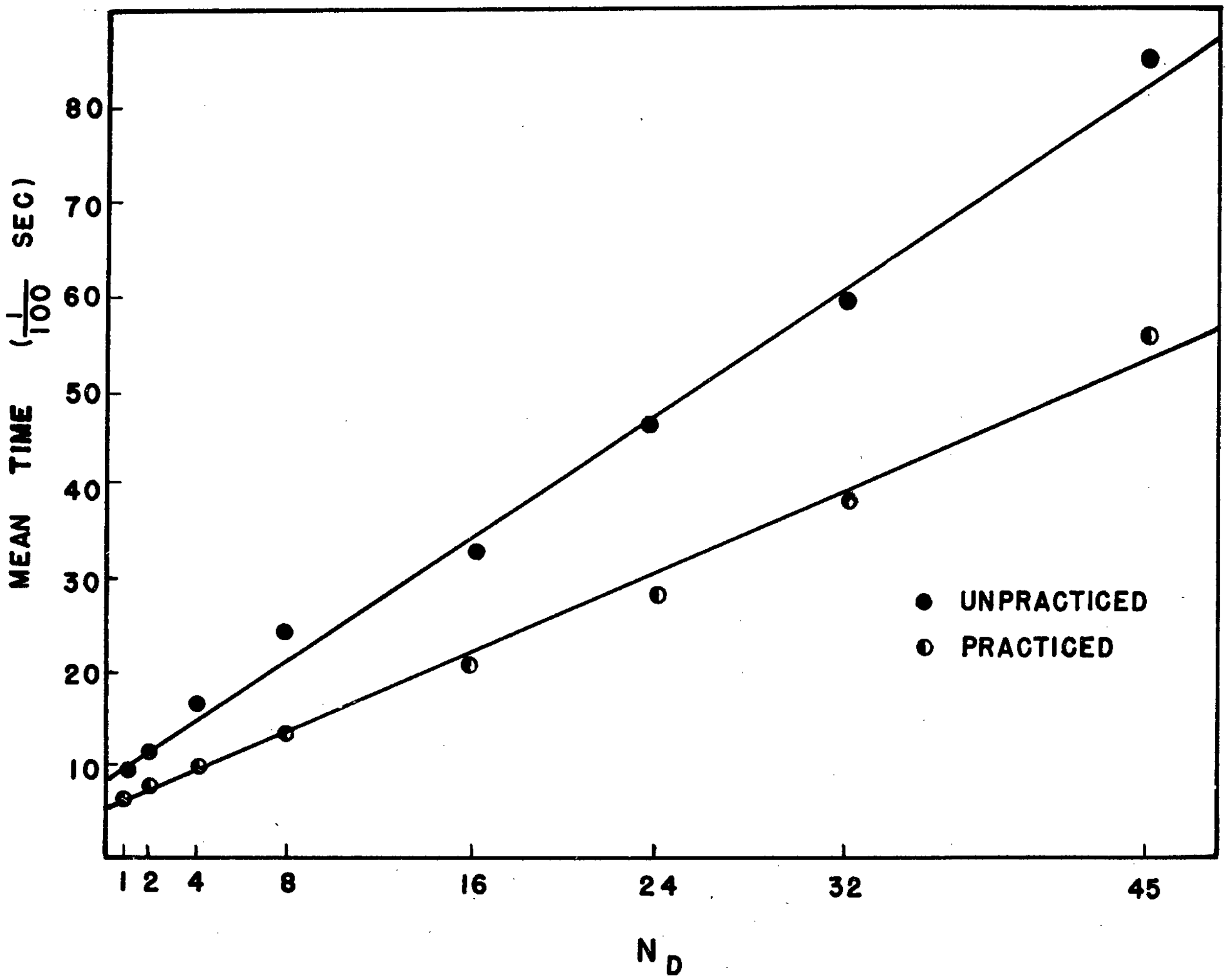



Figure 11. Mean time per panel as a function of $N_D$. The upper curve is the mean of the first eight trials of all groups. The lower curve is for all trials except the first eight.

Both curves are approximately linear, and are described by the equations:

$$t = 1.1\ N_D + 5.2 \quad \text{(practiced subjects)}$$

$$t = 1.7\ N_D + 7.2 \quad \text{(unpracticed subjects)}$$

where t = time in 1/100 seconds. The slope constants, 1.1 and 1.7, represent time per dial, and the intercept constants, 5.2 and 7.2, the time required for the operation of the tachistoscope shutter.

## III. EXPERIMENT II

Experiment I had been concerned entirely with a check-reading situation in which pointers over the whole panel were aligned at the nine o'clock position. Since reading time was found to be a linear function of $N_D$ and a definite value could be given to the slope constant in the equation, it seemed desirable to determine, for comparison, the corresponding constant in a situation where pointer alignment over the whole panel was not the criterion. For this purpose each dial on the panel was marked with a red line which extended for 45° around its circumference. The positions of the red marks on the different dials were randomized. All pointers except one had their tips within the red line area, and the subject was instructed to locate the one dial whose pointer was not within this area.

### APPARATUS, PROCEDURE, SUBJECTS

Except for the modification described above, the apparatus was identical with that used in Experiment I. There were two other modifications of procedure: 1) instead of marking their responses in answer booklets, the subjects looked at representations of the dial panel, located $D_m$, and then described its position to the experimenter. 2) The subject reported pointer position as clockwise or counter clockwise from the red-line area, rather than "up" or "down". Only the white illumination was used, and each subject was tested once on each dial panel. The subjects were the same ones who composed Group III in Experiment I. By this time they were thoroughly practiced, and the results of this experiment, although based on a relatively small number of observations (1536) are probably as reliable as the results obtained from less experienced subjects in Experiment I. About three weeks intervened between the end of Experiment I and the beginning of Experiment II.

### RESULTS

Effect of $N_D$:

In Figure 12, mean time per panel is plotted as a function of $N_D$. The curve for practiced subjects in Experiment I is reproduced here again for comparison. Again the relationship between the variables appears to be linear, but if the line were extrapolated to zero dials, it would be found to have a negative intercept, which is nonsense. We are therefore forced to conclude that between 2 and 45 dials the relationship is linear, but below two dials there is a sudden and pronounced decrease in slope. The slope between 2 and 45 dials for a line fitted by eye turns out to be 18.6 (1/100 sec.) in contrast to the slope of 1.1 (practiced subjects) for the condition where pointers were aligned at the nine o'clock position. This means that if one dial is added to a panel of two or more dials, .186 additional seconds will be required, on the average, to read that panel.

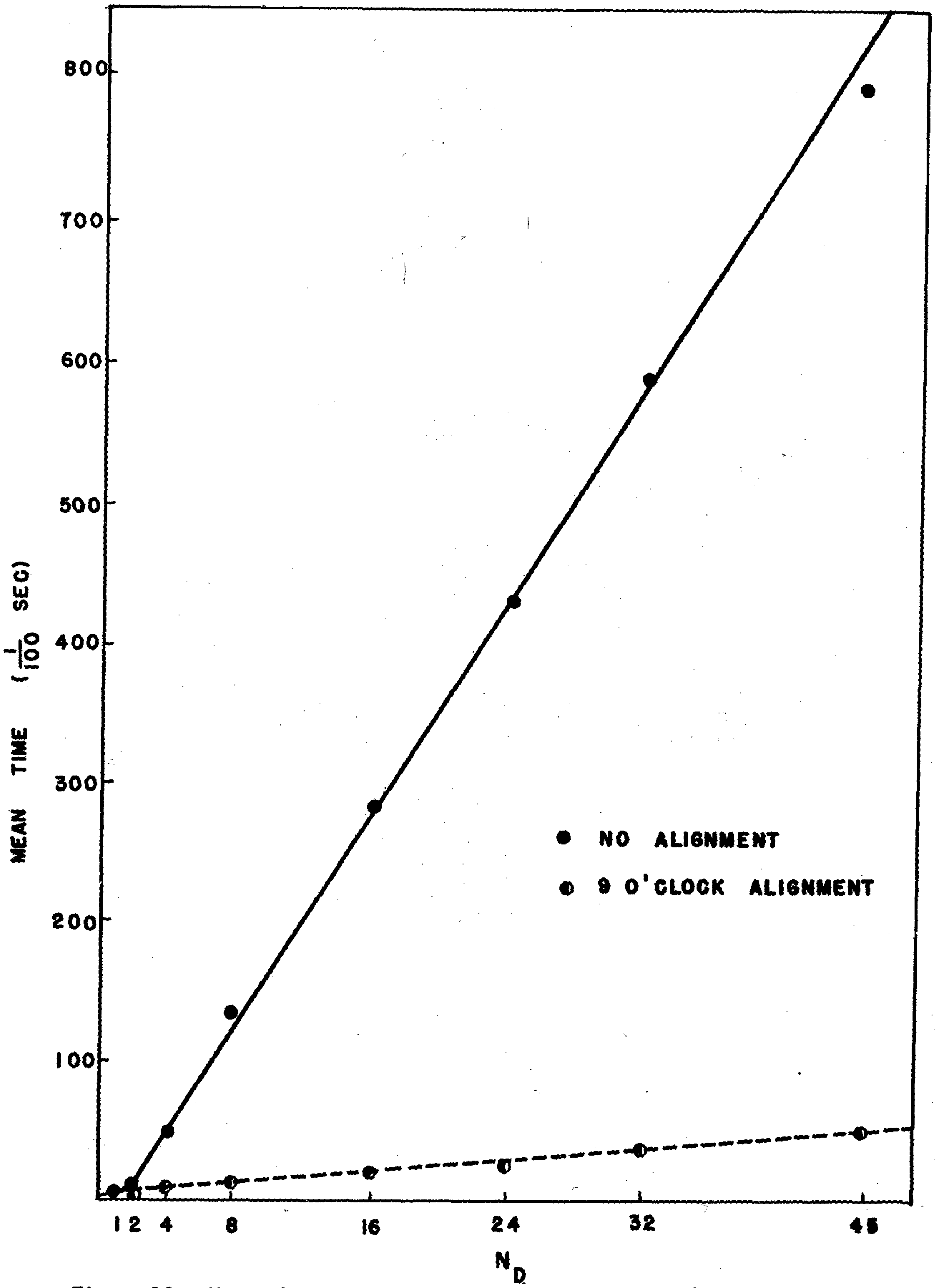



Figure 12. Mean time per panel as a function of $N_D$. Solid circles represent scores when pointers are not aligned; half-solid circles represent scores when pointers are aligned at the 9 o'clock position.

Location of $D_m$:

The mean time per panel was computed for each $D_m$, and the results are presented in Appendix II. Mean times were then computed for each panel as a function of vertical or of horizontal displacement of $D_m$ from the fixation point, and these results are plotted in Figures 13 and 14. These figures should be compared with Figures 6 and 7 which present the comparable data for the condition where pointers are aligned. It will be quickly seen that there are striking differences in the shapes of the curves. With aligned pointers, time tends to increase as distance from the fixation point increases in either direction; without pointer alignment, time increases regularly from top to bottom row, the magnitude of the increase being directly related to $N_D$, and seems to bear no regular relationship to horizontal separation from the fixation point.

A comparison of these two sets of figures suggests that the method of checking or reading the dial panel is entirely different for the two different conditions of alignment. With aligned pointers, the first fixation is probably central, and this may be followed by a shift to any quadrant of the panel, with perhaps a greater probability that the first shift will be to one of the upper quadrants. (In comparing these results with those of White (7) who found that the first fixation was most likely to be in the upper left corner, it should be remembered that his subjects were required to make their preliminary fixation to the side of the panel, whereas ours were required to make their preliminary fixation central.) It also seems likely that peripheral vision is useful in judging alignment, particularly for practiced subjects. When pointers are not aligned, the first fixation is probably not central, in spite of the fact that the subjects were apparently conscientious about using the central fixation point for the preliminary fixation, but someplace in the top row of dials, usually the left. (See tables in Appendix II. The two or three dials at the left end of the top row usually show the shortest times of any on the panel.) Probably some subjects then move their eyes as in reading, from left to right, followed by a jump back to the left end of the next row, while others zig-zag back and forth over the rows. Subjects also reported that under these conditions they would become panicky and start over if they did not locate the deviating pointer quickly. Peripheral vision is probably of little use in judging whether a pointer is in the red-line area.

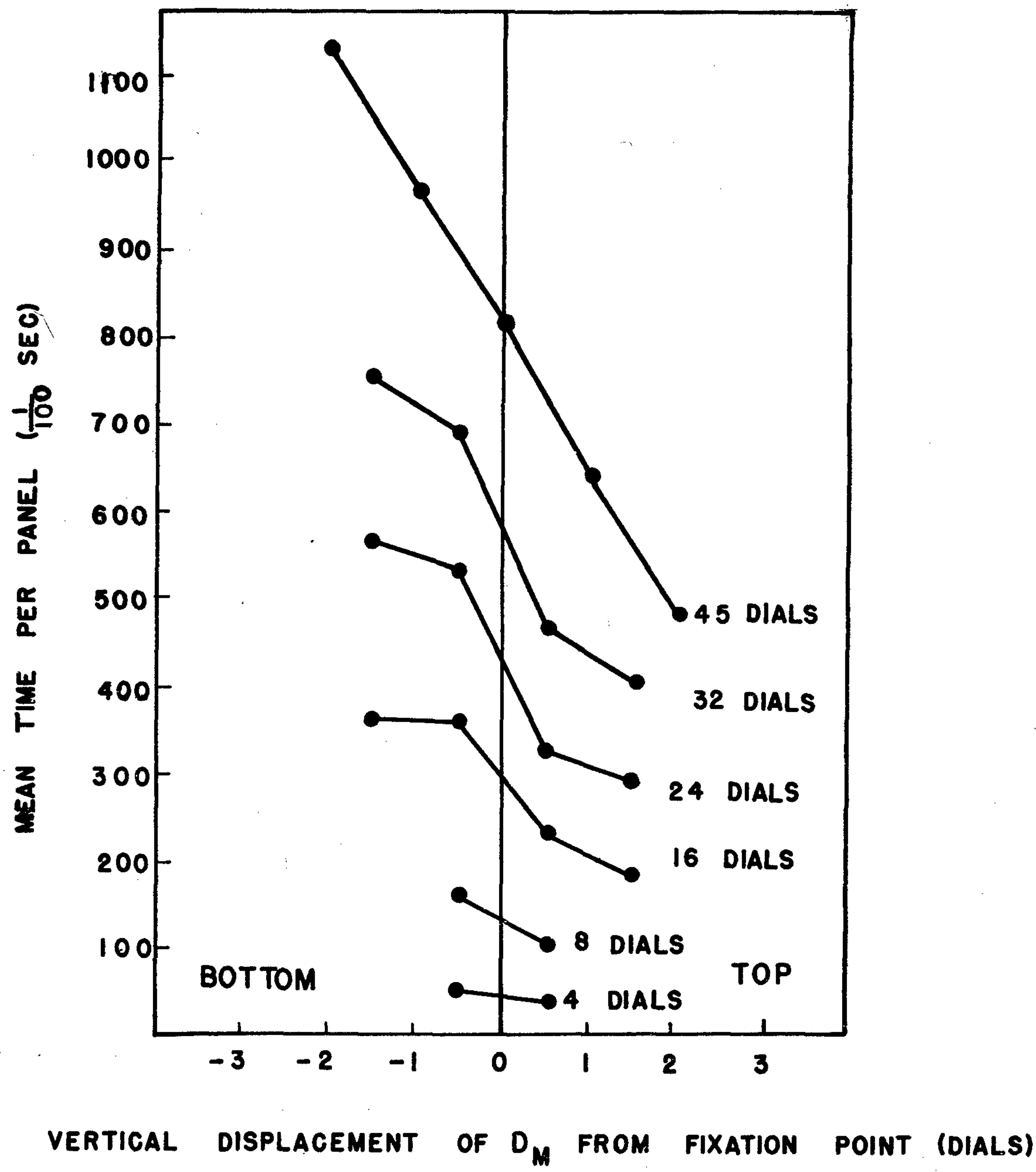



Figure 13. Mean time as a function of vertical displacement of $D_m$ from fixation point. This figure should be compared with Figure 6, but note difference in scale.

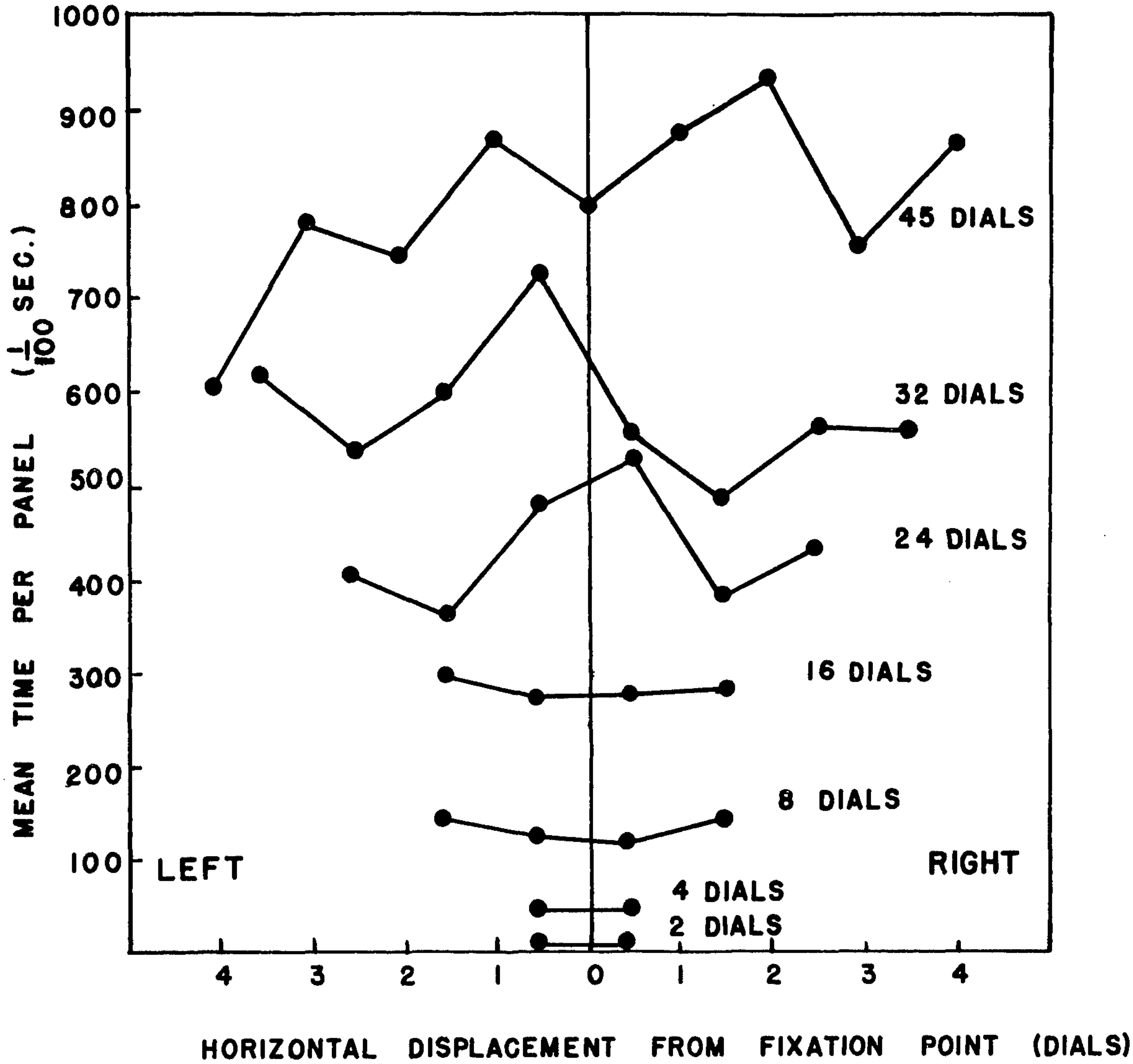



Figure 14. Mean time as a function of horizontal displacement of $D_m$ from fixation point. This figure should be compared with Figure 7, but note difference in scale.

TABLE IV

Mean times and mean $\sigma_i$ in 1/100 sec. as a function of trials.

| | Trials | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| $\bar{X}$ | 342.8 | 297.8 | 279.3 | 311.1 | 289.0 | 270.6 | 253.9 | 275.2 |
| $_i$ | 199.4 | 160.0 | 155.6 | 160.4 | 151.5 | 151.9 | 143.8 | 157.4 |

Practice Effects:

Table IV presents the mean time and mean $\sigma_i$ as a function of trials. It is interesting to note that even these highly practiced subjects show evidence of improvement with practice in the new situation. Both time and variability decrease with practice. This cannot be due to improved methods of operating the tachistoscope, and is probably not due to form-field expansion. The relatively long times on trial 1 may be attributed to part to the effects of three weeks without practice. Improvement probably represents partly recovery from the lay-off, and partly the result of the subjects' experimentation in seeking new ways of coping with their radically altered task.

## IV. EXPERIMENT III*

The fact that reading time is higher when $N_D$ is higher, even when $D_m$ is the central dial of the panel, suggests that the mere presence of unused dials on a panel may increase the difficulty of the reading task. To test this hypothesis a third short experiment was performed.

### APPARATUS, SUBJECTS, PROCEDURE

The apparatus was the same as that used in Experiments I and II. The subjects were two groups of eight Antioch undergraduates. The subject's task was, as previously, to locate $D_m$ and name the direction of pointer misalignment. In Group I, all pointers except that of $D_m$ were aligned at the nine o'clock position as in Experiment I, while in Group II pointers were located within a red-lined sector, as in Experiment II.

The experimental variable was the number of unused dials surrounding those whose pointers could be misaligned. Thus, the usable panel consisted of four dials, arranged in a square. These dials were surrounded either by a plain black background, or by thirty-six unused dials, all forty being ar-

* Experiment III was conducted by Mrs. Avis-Ann Parke.

ranged in a 4 x 10 rectangle. No border or other line of demarcation surrounded the four operative dials. Subjects were told in advance that only four dials would be used, and were given 250 practice trials with a 24 dial panel of which only four dials were actually used. Order of presentation was, of course, counterbalanced.

## RESULTS

The results are summarized in Table V.

TABLE V

Mean times per panel in 1/100 sec.

| | 4 Dials | 40 Dials | t |
|---|---|---|---|
| Aligned Pointers | 15.2 | 15.6 | 0.57 |
| Red-line Condition | 49.1 | 47.9 | 0.27 |

t-tests show that the differences between the two conditions are completely insignificant. Apparently $N_D$ affects reading time only if the added dials are actually used. A context consisting of additional dials does not increase check reading time. These results suggest that time required to locate a given $D_m$ may be some function of the probability of that particular dial's being the one whose pointer is misaligned.

# V. DISCUSSION -- EXPERIMENTS I, II, AND III

The most important, and in many ways the most surprising finding of these experiments is that as the number of dials on a panel increases, the time required to read that panel increases linearly. There are several other ways it might have happened -- time might have remained constant up to some value (possibly the number of dials which could be included within the form-field) and then increased; or time might have been a linear function of the number of bits of information transmitted by the panel. But the relationship is at least roughly linear with respect to $N_D$.

What of extrapolation? Here, of course, we can only conjecture. The linear relationship might continue almost indefinitely, but it would also seem reasonable to suppose that when there were so many dials that head movements were required to look at them all, or when locating the dial required actual counting of rows and columns, more time would be required.

From the data at hand it is impossible to tell whether time is linear with respect to solid angle included in the panel, or with respect to number of dials. Some evidence on this question comes from White's study (7) of the optimum dial size for check-reading a sixteen dial panel whose pointers are aligned horizontally. He found that times differed for different dial sizes, which we would not expect if time were only a function of number of dials. However, times were higher for 1" dials and for 2 1/2" dials than for 1 3/4" dials, which could not occur if time were linearly related to solid angle. Further experimentation will be required to clarify this point. The solid angle may be kept constant and the number of dials within it varied, or the number of dials may be kept constant and the solid angle varied. Such experimentation is presently being planned.

Of interest also is a comparison of the results of Experiments I and II. It takes approximately eighteen times as long to check a panel under the "redline" condition than when all pointers are aligned horizontally. With small panels the absolute amount of time saved is actually fairly small, but with a forty-five dial panel, 7.5 seconds is saved by aligning pointers. In fact the times involved in checking the panel without alignment are almost long enough to permit quantitative reading. The large time differences between these two conditions are undoubtedly due to differences in the use of the eyes in scanning the panel. The evidence indicates that a reading type eye-movement, or a zig-zag pattern is used when pointers are not aligned, whereas eye-movements may be unnecessary or very few in number when pointers are aligned.

Also of interest is the fact that when $D_m$, on one of the larger panels, was the central dial on the panel, reading times were comparable to other times for that panel, rather than to times for the smaller panels. This may be due to the fact that more time is required to identify the dial. The evidence from Experiment III shows that if peripheral dials on a panel are not used, their mere presence has no effect on the time required to read the central dials. This suggests the interesting possibility that, if other conditions are equated, reading time may be some function of the probability of misalignment.

Finally, the fact that the relationship between time and number of dials is linear means that we have a powerful tool for the evaluation of new instrument designs. A standard curve could be determined over a wide range of points with experimental conditions and subjects similar to those to be used in future experimental work. To evaluate a new design, then, a comparison could be made for a single $N_D$, the relation between the mean time for the new design and the standard determined, and the mean time for any $N_D$ could then be predicted. Since it is easier to experiment with small panels, but large ones are more likely to be used in practice, this technique could be a valuable research tool.

## VI. CONCLUSIONS

1. When pointers are aligned at the nine o'clock position, time required to locate one deviating pointer increases as a linear function of the number of dials on the panel between 1 and 45 dials. For practiced subjects the slope of the line is 1.1 x .01 seconds.

2. When pointers are not aligned, but located, rather, within a 45° sector marked with a red line, the time required to locate one pointer not so placed increases as a linear function of the number of dials on the panel between 2 and 45 dials, and the slope of the line, for practiced subjects is 18.6 x .01 seconds.

3. Performance is radically improved by practice. It is hypothesized that this improvement may be due at least in part to the expansion of the visual form-field.

4. With aligned pointers, there is no practical difference between performance with red light of .003 ft. lamberts and white light of 1.5 ft. lamberts. This may be due to the functional "cleaning up" of the panel, under the dim illumination. Subjects report that the graduations of the dials are scarcely visible but the straight horizontal line of the aligned pointers is very prominent.

5. With aligned pointers time increases as the distance between the dial whose pointer is misaligned and the fixation point increases, either vertically or horizontally. When pointers are not aligned, there is no regular relationship between time and the horizontal distance of the misaligned pointer from the fixation point. Time increases consistently from the top to the bottom of the panel, and the magnitude of the increase is greater for the larger panels.

6. From the differences in time as a function of displacement of the dial from fixation point, it is hypothesized that the nature of the eye-movements under the two reading conditions may be quite different.

7. Time required to check-read a four dial panel is not increased by surrounding these dials by thirty-six unused dials. Not number of dials, but number of "operating" dials, is the significant variable.

APPENDIX I

Experimental design within a block (group and illumination condition). Numbers in cells are $N_D$. Each $N_D$ occurs once in each trial, and each $N_D$ follows every other $N_D$ once.

| Subject | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Trial | | | | | | | | |
| 1 | 1 | 2 | 4 | 8 | 16 | 24 | 32 | 45 |
| 2 | 2 | 4 | 8 | 16 | 24 | 32 | 45 | 1 |
| 3 | 8 | 16 | 24 | 32 | 45 | 1 | 2 | 4 |
| 4 | 32 | 45 | 1 | 2 | 4 | 8 | 16 | 24 |
| 5 | 4 | 8 | 16 | 24 | 32 | 45 | 1 | 2 |
| 6 | 45 | 1 | 2 | 4 | 8 | 16 | 24 | 32 |
| 7 | 24 | 32 | 45 | 1 | 2 | 4 | 8 | 16 |
| 8 | 16 | 24 | 32 | 45 | 1 | 2 | 4 | 8 |

APPENDIX II

TABLE VI

Time per panel when each dial was the one whose pointer was misaligned. Experiment I.

| $N_D$ | | | | | $\bar{X}$ |
|---|---|---|---|---|---|
| 1 | 7.9 | | | | |
| 2 | 9.4 | 9.2 | | | 9.3 |
| 4 | 12.3 | 12.5 | | | 12.4 |
| | 12.5 | 12.5 | | | 12.5 |
| $\bar{X}$ | 12.4 | 12.5 | | | |
| 8 | 15.5 | 15.0 | 15.2 | 15.8 | 15.4 |
| | 16.0 | 15.5 | 15.8 | 17.9 | 16.3 |
| $\bar{X}$ | 15.8 | 15.2 | 15.5 | 16.8 | |
| 16 | 24.4 | 24.5 | 25.4 | 25.0 | 24.8 |
| | 25.1 | 21.7 | 23.4 | 22.7 | 23.2 |
| | 24.8 | 23.8 | 24.3 | 23.8 | 24.2 |
| | 26.4 | 25.1 | 26.4 | 30.1 | 27.0 |
| $\bar{X}$ | 25.2 | 23.8 | 24.9 | 25.4 | |

TABLE VI (cont'd)

| $N_D$ | | | | | | | | | | $\bar{X}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | 36.4 | 33.7 | 33.4 | 35.2 | 36.4 | 37.3 | | | | 35.4 |
| | 33.9 | 31.2 | 31.1 | 31.3 | 32.9 | 35.1 | | | | 32.6 |
| 24 | 39.5 | 36.7 | 33.2 | 34.6 | 31.2 | 35.3 | | | | 35.1 |
| | 41.7 | 39.7 | 35.8 | 37.4 | 42.9 | 38.6 | | | | 39.4 |
| $\bar{X}$ | 39.7 | 35.3 | 33.4 | 34.6 | 35.8 | 36.6 | | | | |
| | 55.3 | 55.3 | 38.4 | 41.7 | 43.3 | 41.1 | 44.0 | 47.8 | | 45.9 |
| | 59.9 | 49.1 | 36.3 | 37.2 | 40.6 | 41.2 | 40.8 | 46.0 | | 43.9 |
| 32 | 65.8 | 42.7 | 43.8 | 38.2 | 35.3 | 42.7 | 43.1 | 43.1 | | 44.3 |
| | 57.2 | 53.5 | 52.4 | 43.5 | 39.8 | 48.2 | 45.0 | 55.8 | | 49.4 |
| $\bar{X}$ | 59.6 | 50.1 | 42.7 | 40.2 | 39.8 | 43.3 | 43.2 | 48.2 | | |
| | 55.8 | 79.9 | 61.4 | 56.9 | 57.4 | 44.8 | 91.3 | 71.3 | 71.4 | 65.6 |
| | 97.2 | 75.2 | 49.4 | 50.2 | 54.9 | 54.7 | 66.6 | 68.5 | 81.4 | 66.5 |
| 45 | 77.8 | 71.1 | 45.9 | 59.6 | 47.8 | 51.7 | 48.6 | 70.7 | 72.3 | 60.6 |
| | 89.5 | 83.9 | 59.5 | 51.6 | 51.4 | 61.2 | 55.0 | 52.5 | 119.9 | 69.4 |
| | 75.4 | 112.9 | 82.9 | 63.7 | 52.2 | 63.6 | 72.7 | 111.7 | 79.2 | 79.4 |
| $\bar{X}$ | 79.1 | 84.6 | 59.8 | 56.4 | 55.0 | 55.2 | 66.8 | 74.9 | 84.8 | |

TABLE VII

Experiment II. Time per panel when each dial was $D_m$.

| $N_D$ | | | | | $\bar{X}$ |
|---|---|---|---|---|---|
| 1 | | 5.4 | | | |
| 2 | | 11.2 | 11.6 | | 11.4 |
| 4 | | 44.9 | 45.4 | | 45.2 |
| | | 58.4 | 56.7 | | 57.6 |
| | $\bar{X}$ | 51.6 | 51.1 | | |
| 8 | | 121.4 | 111.8 | 88.8 | 129.7 | 112.9 |
| | | 181.5 | 149.0 | 162.0 | 167.9 | 165.1 |
| | $\bar{X}$ | 151.4 | 130.4 | 125.4 | 148.8 | |
| 16 | | 165.0 | 170.0 | 266.4 | 145.5 | 186.7 |
| | | 220.8 | 211.4 | 236.4 | 288.8 | 239.4 |
| | | 454.2 | 364.5 | 277.7 | 384.2 | 361.2 |
| | | 367.1 | 379.3 | 352.7 | 354.9 | 363.5 |
| | $\bar{X}$ | 301.8 | 281.3 | 283.3 | 284.4 | |

| $N_D$ | | | | | | | | | | $\bar{X}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 248.8 | 258.2 | 305.6 | 375.5 | 273.5 | 322.0 | | | | 297.3 |
| | 303.2 | 255.8 | 337.4 | 554.5 | 248.1 | 292.2 | | | | 331.9 |
| | 473.6 | 417.0 | 628.6 | 650.5 | 468.2 | 600.4 | | | | 539.7 |
| | 600.9 | 545.2 | 638.5 | 540.1 | 544.9 | 530.0 | | | | 566.6 |
| $\bar{X}$ | 406.6 | 369.0 | 477.5 | 530.2 | 383.7 | 436.2 | | | | |
| 32 | 582.9 | 499.8 | 172.0 | 607.2 | 321.4 | 316.0 | 325.0 | 450.1 | | 409.3 |
| | 503.4 | 463.2 | 580.5 | 730.5 | 482.4 | 339.9 | 315.5 | 363.0 | | 472.3 |
| | 639.0 | 611.8 | 857.9 | 799.8 | 574.8 | 592.4 | 777.6 | 720.8 | | 696.8 |
| | 746.8 | 587.2 | 796.9 | 770.6 | 859.2 | 716.7 | 847.8 | 698.5 | | 753.0 |
| $\bar{X}$ | 618.0 | 540.5 | 601.8 | 727.0 | 559.4 | 491.2 | 566.5 | 558.1 | | |
| 45 | 309.2 | 273.8 | 342.2 | 490.8 | 677.6 | 664.8 | 576.4 | 269.8 | 756.0 | 484.5 |
| | 390.3 | 1013.0 | 485.2 | 705.5 | 386.0 | 618.2 | 546.5 | 553.4 | 910.0 | 623.1 |
| | 604.5 | 499.0 | 661.8 | 1267.5 | 783.2 | 805.2 | 1046.8 | 955.0 | 766.2 | 821.0 |
| | 584.2 | 976.6 | 1259.8 | 772.5 | 964.0 | 1229.2 | 1334.5 | 762.5 | 825.0 | 967.6 |
| | 1130.0 | 1158.2 | 975.6 | 1101.8 | 1190.8 | 1105.5 | 1148.5 | 1250.0 | 1017.4 | 1119.8 |
| $\bar{X}$ | 603.6 | 784.1 | 744.9 | 867.6 | 800.3 | 884.6 | 930.5 | 758.1 | 854.9 | |

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